MHD velocity distribution and pressure drop in manifolds of a WCLL TBM

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Introduction

- In liquid metal blankets, lead lithium PbLi is foreseen as breeder, neutron multiplier, heat transfer medium.
- Flowing PbLi interacts with the plasma-confining magnetic field. Electric currents are induced that cause electromagnetic forces, high pressure drop and a distribution of electric potential inside fluid and electrically conducting walls.
- The design of manifolds which distribute PbLi into the WCLL TBM breeder zones is shown in Fig.1a. They consist of two poloidal ducts, electrically connected across a common wall.

WCLL TBM design and model geometry

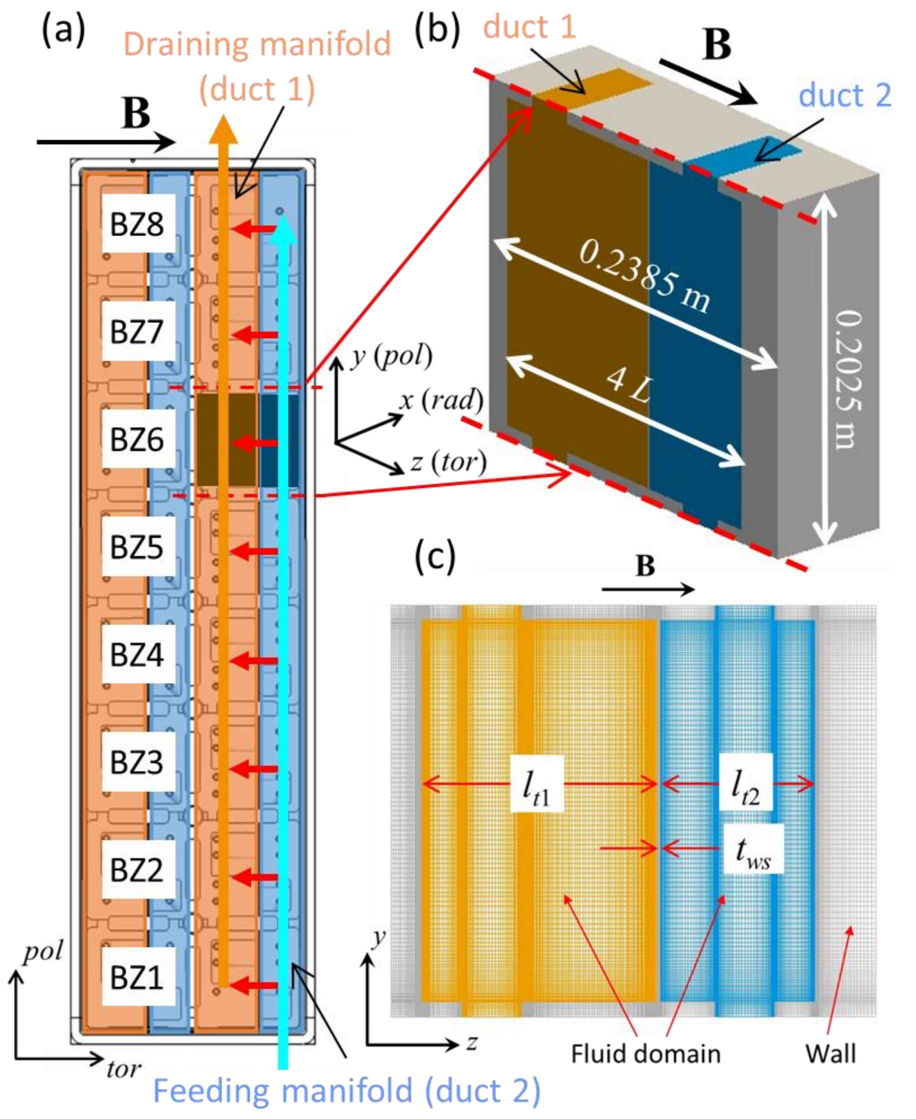


Fig.1 (a) Design of WCLL TBM manifold. Cyan arrow indicates PbLi path in feeding manifold, the red ones the transition across breeder units, orange arrow the path in collecting manifold. (b) Model geometry for simulations. A uniform magnetic field is imposed in toroidal direction. (c) Computational mesh for fluid and wall.

- Simulations are performed for periodic fractions of the manifolds by assuming stepwise decrease/increase of flow rate in feeding/draining manifolds (Fig.1b).
- Velocity and pressure distributions in the entire manifolds that feed/drain 8 breeder zones are then reconstructed.

Parameters characterizing the MHD flow

Hartmann number	$Ha = LB_0\sqrt{\dfrac{\sigma}{\rho\nu}}$	Non-dimensional measure for magnetic field strength B_0
Reynolds number	$Re = \dfrac{u_0 L}{\nu}$	Non-dimensional measure for mean velocity u_0 in breeding zone
	$L = (l_{t1} + t_{ws} + l_{t2})/4 = 0.048375$ m	Typical length (Fig.1c)

Numerical results

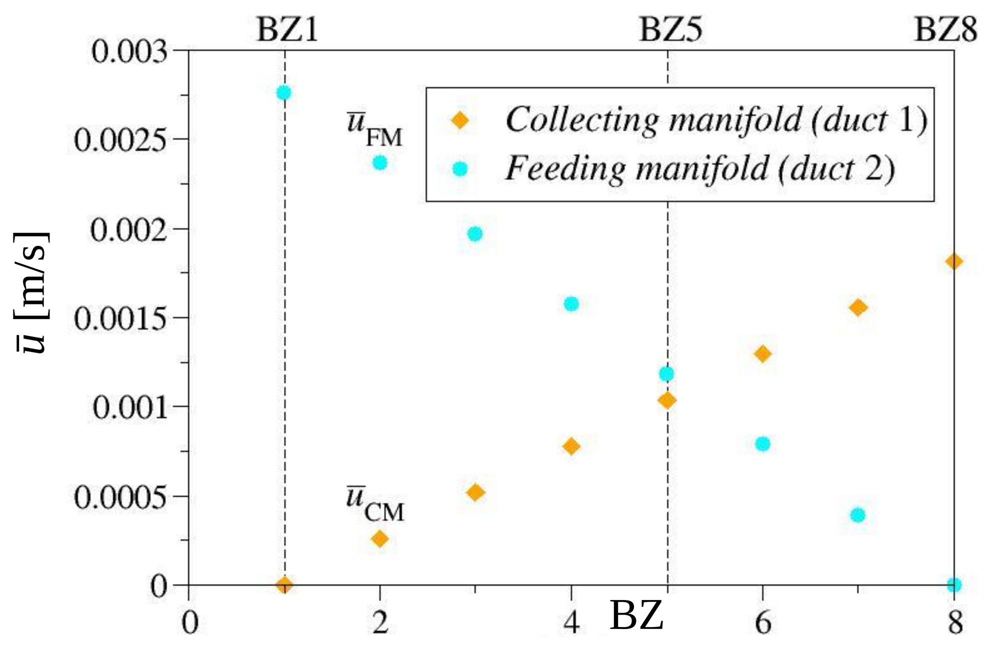
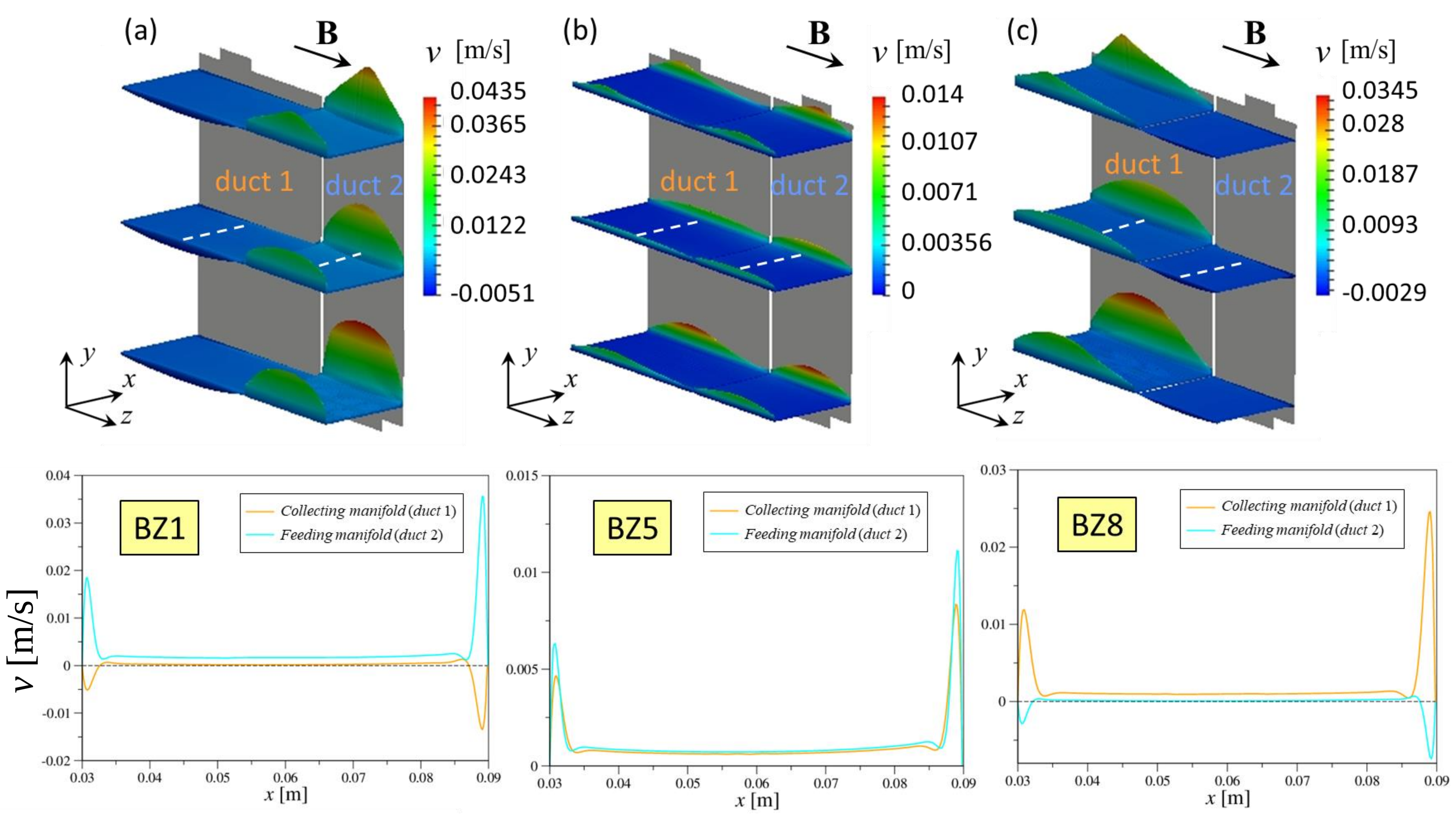


Fig.2. Mean velocities that drive the flow in manifolds in each portion of the blanket module corresponding to a specific breeding zone (BZ). Different parts of manifolds along the poloidal direction are referred to as BZ1,..., BZ8 (Fig.1a)

Velocity distribution

$Ha = 4000 \quad u_0 = 0.1$ mm/s



- Increased velocity in side layers, along walls parallel to the magnetic field **B**, reduced velocity in the duct cores
- Significant 3D MHD effects near expansions and contractions, since the flow expands/contracts in **B** direction
- Strong influence of electromagnetic coupling of flows in adjacent fluid domains. As an example consider the flow in BZ1 in Fig.2a:
  - due to e.m. coupling flow in duct 2 pulls the one in the core of duct 1 in same direction
  - the resulting buildup of pressure drives reversed jets in duct 1

Fig.2 Flow at Ha = 4000, u_0 = 0.1mm/s, (a) at the bottom of the module in BZ1, (b) in the middle in BZ5, (c) at the top in BZ8 (see Fig.1a). Above, 3D views of velocity distribution at three poloidal locations. Below, profiles of vertical velocity along the radial x coordinate, in the middle of the ducts.

Pressure distribution

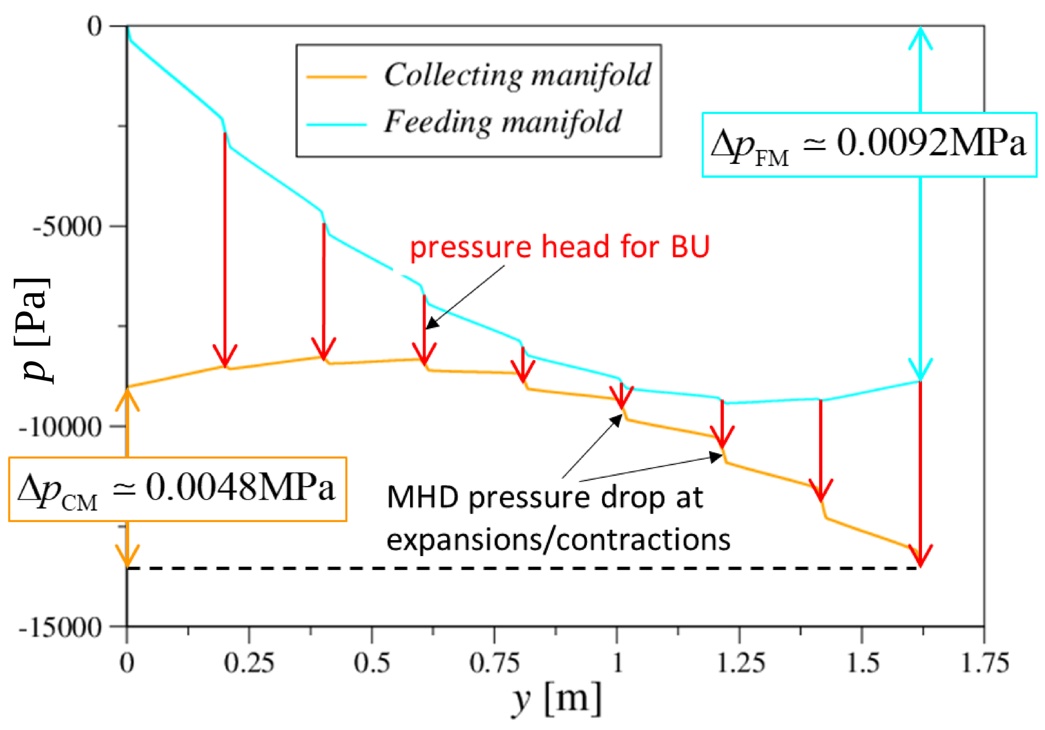


Fig.3 Pressure along the poloidal direction in feeding and draining manifolds (see Fig.1a) for flow at Ha = 4000, u_0 = 0.1mm/s.

- First estimation of pressure drop in manifolds of WCLL TBM gives acceptable values (Fig.3)
  → Other contributions should be considered, such as Δp in long PbLi supplying pipes
- Numerical results confirm scaling for MHD pressure drop under strong **B**, $\Delta p \sim \sigma L B^2 u_0$
- Mean velocity along feeding/draining manifold decreases/increases in poloidal direction
- Pressure drop along feeding/draining manifold decreases/increases in pol direction

➡ Pressure head between entrance and exit of breeder zones is not the same (see red arrows in Fig.3)

➡ Partitioning of liquid metal among the breeding zones is not uniform

➡ Flow imbalance is due to current manifold geometry in TBM design: cross-section of coupled ducts remains on average constant along poloidal fluid path, while flow rate changes by passing from BZ1 to BZ8.

EUROfusion

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The views and opinions expressed herein do not necessarily reflect those of the European Commission.